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# DYNAMIC LOADING OF TEFLON AT 200°C

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**Abstract.** Dynamic loading experiments were performed on inert Teflon (Polytetrafluoroethylene) samples, initially heated to the temperature of 200°C, to test its behavior under these conditions for its use in other heated experiments. Tests were performed in the 100 mm diameter bore propellant driven gas gun with piezo-resistive manganin pressure gauges imbedded into the samples to measure loading pressures. Experimental data provided new information on the shock velocity – particle velocity relationship for the heated material and showed no adverse effect of temperature on the insulating properties of the material.

**Keywords:** Shock compression, polymer, equation of state
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## INTRODUCTION

Polytetrafluoroethylene (PTFE-Teflon) is widely used in shock initiation experiments of various explosives as inert armor of the in situ piezo-resistive pressure gauges. This armor serves as an electrical insulator of the gauges from the reactive products of the explosives, which become conductive after they start to chemically react as result of being dynamically loaded by impact.

To accurately model the results of dynamic loading scenarios and compare them with the experimental data, one has to take into account all the components of the testing assembly, which includes the imbedded gauge packages with armor material. One must also know how armor material behaves under various testing conditions, such as shock and heat, so that it will not impair the performance of the gauges.

## EXPERIMENTAL PROCEDURE

The dynamic loading experiments were performed on the 100 mm bore propellant driven gas gun, which allows precise control of the projectile velocity and of the loading pressure imposed on the target material. The experimental set-up is illustrated in Fig. 1.

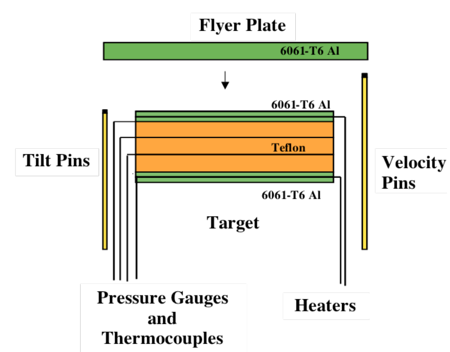


**FIGURE 1**. Target assembly for the heated Teflon gun experiment.

The target assembly consisted of several discs of the investigated material. Gauge packages, consisting of 25 $\mu$m thick manganin pressure gauges armored on both sides with thin 125 $\mu$m Teflon insulation sheets, were placed between the discs. Manganin gauges have been used successfully in numerous one-dimensional loading experiments. These have also been shown to be temperature insensitive [1]. The gauges were of the four terminal variety, described in our earlier publication [2], where two of the terminals were used to drive the gauge element with a constant current of 50 A, and the other two were used to read the change in voltage across the gauge element when the resistance of the gauge changes due to imposed pressure. This voltage trace is then converted to pressure using the hysteresis corrected curve published elsewhere [3].

For better control of the impact pressure, a thin buffer plate of the same material as the impact plate is placed in front of the target assembly for symmetrical impact. Also included in the target assembly are six tilt pins placed around the periphery of the target flush with the impact surface to measure the tilt of the impact plate as it strikes the target, and four velocity pins sticking out some known distance from the target to measure the velocity of the impact plate just before it strikes the target.

To heat the Teflon target assembly two Aluminum discs were placed on both sides of the target with a flat Nichrome spiral ribbon heater between them. Aluminum discs were used to provide faster and more uniform heat distribution to the target assembly. In these experiments the gauge packages also contained thermocouples of the same thickness as the manganin pressure gauges. The thermocouples were used to monitor the temperature of the assembly during the heating process. The heating was done at the rate of 1.5°C per minute until the desired temperature was reached. Since Teflon is an insulator, both electrical and thermal, the target assembly had to be held at final temperature for at least 45 minutes to attain a uniform temperature across the whole assembly before the shot was fired.

## AMBIENT TEFLON

The material used in these experiments was commercial ASTM – 1710 PTFE – Teflon (Polytetrafluoroethylene) with density of 2.161 g/cc. Before testing the hot Teflon for its behavior under shock loading, several shots were fired at ambient conditions to confirm the Hugoniot data available in the literature [4-6]. For ambient experiments the gauge packages did not include the thermocouples, and the back plate was not made of Aluminum but rather of PMMA (Polymethylmethacrilate). The front buffer plate was still Aluminum to provide a symmetrical impact with the Aluminum flyer plate. A typical record of such ambient experiment is illustrated in Fig. 2. It shows a steady pressure of 11.27 GPa, propagating through the first five gauges. The last gauge is affected by the release wave that comes from the rear side of the impacting flying plate.

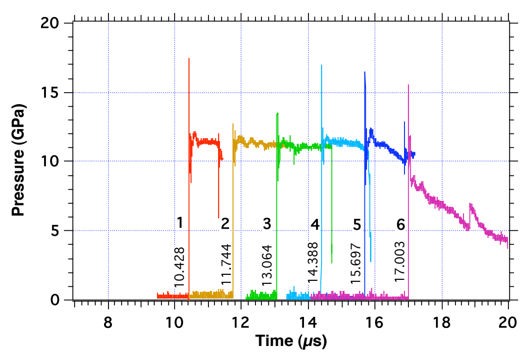


**FIGURE 2**. Pressure gauge traces of an ambient Teflon experiment where the target was subjected to dynamic loading of 11.27 GPa by an Aluminum flyer plate impacting it with a velocity of 1.94 mm/$\mu$s.

If the Hugoniot parameters of the ambient flyer material in the form of its shock velocity – particle velocity ($U_s$ - $u_p$) relationship are a priori known, one can construct inverse adiabats of that material on the P – $u_p$ plane, originating from the flyer velocity on the zero pressure axis. Experimental pressure measurement located on that adiabat reveals the particle velocity behind the shock. The measured shock velocity provides the point on the $U_s - u_p$ plane. Having three or more such experimental records one can deduce the desired $U_s - u_p$ relationship of that material, which is valid within the experimental pressure range. This process is illustrated in Fig. 3, which shows a very good agreement of our data with those shown in References 4, 5 and 6.

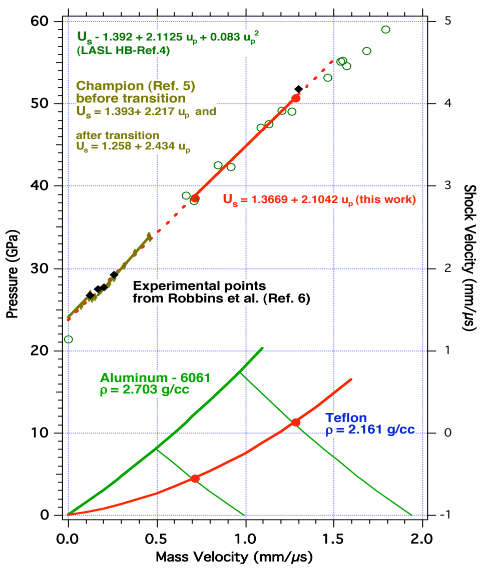


**FIGURE 3**. Impedance matching technique used to determine the $U_s - u_p$ relationship for the ambient Teflon. Data from References 4 - 6 are also shown for comparison.

## HEATED TEFLON

A similar approach was taken to determine the behavior of Teflon initially heated to 200˚C and loaded dynamically to pressures of 9.53, 6.4 and 3.87 GPa. Density of the hot Teflon was determined by using the linear thermal expansion coefficient (TEC) which was measured statically on a Thermal Mechanical Analyzer (TMA) [7]. The measured value of TEC, $\varepsilon = 0.00015$ mm/mm/˚C, yielded the density of hot Teflon to be $\rho_h = 2.0032$ g/cc. One of such records is shown in Fig. 4 with the release wave from the rear of the flying plate overtaking the shock wave just before it reaches the fifth gauge. Unfortunately, due to the severe environment, gauge 1 broke as soon as it reached the shock pressure and gauge 2 malfunctioned. Figure 5 illustrates the combined $P - u_p$ and $U_s - u_p$ diagram for all three experiments revealing the new $U_s - u_p$ relationship for hot Teflon.

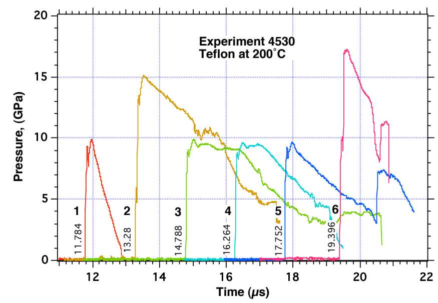


**FIGURE 4**. Pressure gauge traces for the heated Teflon experiment where the target was subjected to dynamic loading of 9.53 GPa by an Aluminum flyer plate impacting it with a velocity of 1.82 mm/$\mu$s.

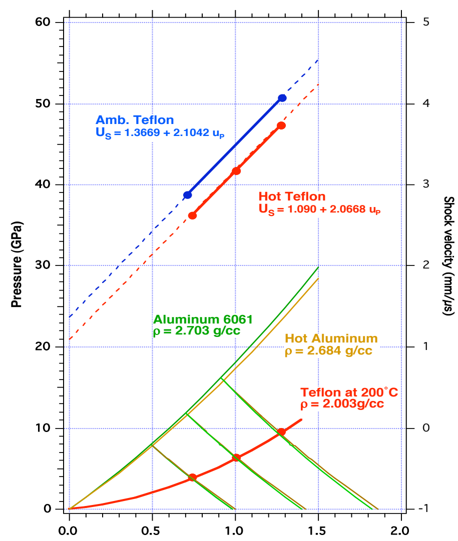


**FIGURE 5.** Impedance matching technique used to determine the $U_s - u_p$ relationship for the Teflon initially preheated to the temperature of 200 ˚C.

A listing of all the experiments done on ambient and hot Teflon with pertinent results is shown in Table 1. Table 2 shows our shock velocity – mass velocity relationship for both ambient and hot Teflon together with ambient values found in Ref. 4-6 for comparison.

**Table 1. Listing of all the experiments done on ambient and hot Teflon.**

| Exp. # | Temp. ˚C | Density g/cc | Flyer Velocity mm/μs | Mass Velocity mm/μs | Shock Velocity mm/μs | Pressure GPa |
|---|---|---|---|---|---|---|
| 4527 | 25 | 2.161 | 1.936 | 1.28 | 4.07±0.02 | 11.27±0.2 |
| 4528 | 25 | 2.161 | 0.993 | 0.71 | 2.86±0.05 | 4.39±0.4 |
| 4530 | 200 | 2.003 | 1.823 | 1.28 | 3.73±0.11 | 9.53±0.5 |
| 4531 | 200 | 2.003 | 1.399 | 1.01 | 3.17±0.1 | 6.40±0.2 |
| 4532 | 200 | 2.003 | 0.983 | 0.74 | 2.62±0.3 | 3.88±0.2 |

**Table 2. Shock velocity – Particle velocity relationships for ambient and hot (200˚C) Teflon.**

$$U_s = a + b\, u_p + c\, u_p^2$$

| | a | b | c | Ref |
|---|---|---|---|---|
| **Ambient** | 1.392 | 2.113 | 0.083 | 4 |
| **Ambient** | 1.393 | 2.217 | 0 | 5, 6 |
| **Ambient** | 1.367 | 2.104 | 0 | Present work |
| **200°C** | 1.09 | 2.067 | 0 | Present work |

## SUMMARY

New experiments have provided the confirmation of the old shock velocity – particle velocity relationship for ambient PTFE – Teflon, which was available in the literature, and have provided the $U_s$ - $u_p$ relationship for the same Teflon initially preheated to a temperature of 200˚C.


## ACKNOWLEDGEMENTS

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